HYDROGYRO SHIP STABILIZER AND METHOD FOR STABILIZING A VESSEL

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application 60/556,398, filed March 25, 2004.

BACKGROUND

Field of Inventions

[0002] Embodiments of the present invention generally relate to a marine craft. Preferred embodiments relate to the stabilization of marine craft by minimizing rolling and / or pitching motion. Further still, embodiments relate to the use of a spinning liquid mass in order to minimize oscillation in a marine vessel.

Description of Related Art

[0003] A gyroscope mounted with its single gimbal axis orthogonal to the major axis of a ship serves to limit rolling motion. Further, a gyroscope mounted with the gimbal axis parallel to the major axis of the ship reduces pitching motion. The gyroscope uses angular momentum and precession to counter these oscillations. Larger vessels require a larger gyroscopic system that can provide greater stabilization forces, while smaller vessels may employ a smaller gyroscopic system.

[0004] The utility of gyroscopes as a means of stabilizing watercraft has been known for many years. Stabilization increases passenger comfort and safety, reduces wear and tear on equipment, and increases the accuracy of warship artillery. An early gyroscope patent is U.S. Patent No. 1,150,311, which issued in 1915 to inventor Elmer A. Sperry. The ‘311 patent was entitled “Ship’s Gyroscope.” Mr. Sperry’s gyroscope employed a large, solid spinning mass that precessed about gimbal bearings. The gimbal bearings were connected to a frame. The frame, in turn, was operatively connected to the hull of a ship.

[0005] Mr. Sperry's gyroscope was utilized by the U.S. Navy as an early gyro-stabilizer system. According to one publication, the gyro was installed aboard a small 700 ton destroyer, and in a submarine. Using the centrifugal motion of the spinning mass, gyrsoscopic forces were transmitted to the hull of the naval vessels through the gimbal axis. Depending upon the orientation of the gimbal axis, the gyroscopic forces could stabilize a floating vessel either as to pitch or as to roll.

[0006] Mr. Sperry's gyroscope was "active" in operation, rather than "passive." In this respect, the Sperry gyroscope used a small gyroscope that sensed the onset of rolling motion. This small gyroscope was electrically connected to the switch of a motor that actuated a precessional gear mounted on a much larger gyroscope. A small gyroscope is more sensitive to rolling motion at inception than a large gyroscope. By activating the motor connected to the precessional gear of the large gyroscope, the large gyroscope was forced to precess at the moment it was needed. Further the motor can increase or decrease the angular velocity of precession to increase or decrease the stabilizing torque as needed based on the magnitude of the external torque. This "active" gyroscope system is preferable in many cases to a "passive" system because the rotor on an "active" gyroscope can be smaller.

[0007] Stabilizing torque of a gyroscope is a function of several factors. These include mass of the flywheel, or "rotor," angular velocity of the rotor, radius of the rotor, and angular velocity of precession of the rotor when subject to an external torque. In order to provide stabilization for a large vessel such as a war ship, Mr. Sperry's ship gyroscope was required to utilize a large metal rotor having a great deal of mass. According to one publication, Mr. Sperry's gyroscope as utilized by the U.S. Navy weighed 5 tons.

[0008] The manufacture of such a device was and remains understandably expensive. In addition, the added weight of the gyroscope increases the fuel consumption of the vessel when in transit. As a result, technologies such as the "active fin" system were developed after World War I to utilize gyroscopic forces in a more indirect manner, permitting the use of smaller gyroscopes. The fin method was preferred to Sperry's ship gyroscope in part due to the much lower weight requirement. Additional

background can be found in U.S. 3,389,674 to Pratt, U.S. 2,104,226 to Gonzales, DE 11 01 205 to Salomon, SU 1,601,022 to Moscovskii Avtomobilno Dorozhnyj Institute as reported in Derwents, U.S. 2,953,925 to Yeadon, FR 2 220 416 to Alsthom and JP 54 124494 to Ishikawajima Harima Heavy Ind. Co. Ltd. as reported in Patent Abstracts of Japan.

[0009] The use of active fins to reduce roll continues today. The active fin system works using a small gyroscope that senses rolling motion and sends a signal to move hull-mounted external fins that counter the motion. However, the active fin system requires that the ship be moving. The active fins are of no value in eliminating oscillations of marine vessels that are at rest. In order to eliminate oscillations of a ship at rest, one or more larger gyroscopes operatively connected to the ship's hull would have to be reintroduced. This has generally proved to be impractical and / or cost-prohibitive.

[0010] An important activity that requires stabilization of marine vessels that are at rest is the extraction and transport of hydrocarbons. A few examples of such vessels are membrane liquefied natural gas (LNG) tankers, offshore workboats, drill ships, floating production storage and offloading vessels (FPSO's), catenary anchor leg mooring buoys ("CALM" buoys), and oceanographic survey vessels.

[0011] Membrane LNG tankers cannot be loaded or offloaded in certain sea states, as excessive roll and pitch motion creates sloshing of liquid within the tanker. Excessive sloshing of large volumes of LNG can cause damage to the containment tanks. Because of this, LNG tankers must postpone loading or offloading when certain heavy seas are forecast. Therefore, a method to stabilize LNG tankers during loading or offloading would increase the integrity of these vessels and reduce vessel standby time.

[0012] Offshore oil and gas platforms need frequent resupply from land. This resupply is performed using workboats that tie up to the platform while a crane is used to transfer supplies to the platform. The transfer becomes increasingly difficult and hazardous as seas become rough. Thus, stabilization of the workboat is desired.

[0013] Drill ships oftentimes operate in rough seas. Weather and marine forces act against drill ships to reduce their operability. A particularly difficult operation in rough seas is the movement of large stands of vertical pipe into and out of a borehole. In addition, while drilling proceeds the drill pipe travels from the drilling rig down to the seafloor inside a riser pipe. Excessive rolling motion of the ship can cause the drill pipe to contact the riser pipe. This contact, and extreme motion in general, increases the risk of failure of the riser and equipment stress/fatigue in general. Thus, stabilization of drill ships will increase their operability and integrity.

[0014] Floating production storage and offloading vessels (FPSO's) typically remain moored for long periods of time. The natural oscillatory motion applied by the ocean to these vessels increases the rate of fatigue of mooring lines and other equipment. Also, large motions can decrease the efficiency of certain oil-water separation equipment that require quiescent conditions. A large vessel stabilizing gyroscope installed on an FPSO would decrease equipment fatigue and increase oil-water separation efficiency.

[0015] Mooring line fatigue is also an issue with buoys, such as catenary anchor leg mooring buoys, known as "CALM" buoys. Thus, stabilization of CALM buoys is desired.

[0016] Oceanographic survey vessels require stability during certain critical measurements. Likewise, seismic vessels need stability during operations.

[0017] Stabilization is also desirable in rescue craft and pleasure boats. Placement of an appropriately-sized gyroscope would aid in providing treatment and comfort to a rescued worker, and would minimize debilitating sea sickness of all passengers. However the placement of solid mass gyroscopes in smaller vessels is not always practical.

[0018] High-speed boat racing is a particularly hazardous activity. It is not uncommon for these boats to lose control and become airborne. This result occurs when control of the attitude of the boat is lost in choppy water. Those of ordinary skill in the art will appreciate that "attitude" refers to the orientation of a craft relative

to the direction of its motion. A gyroscope mounted along the hull of a racing boat would act to maintain the attitude of a racing boat while the boat is in motion. It would do this by countering the forces that would act to change the boat's attitude at inception when these forces are still weak. Thus, an appropriately designed gyroscope could increase the integrity of high-speed racing boats.

[0019] Therefore, there is a need for a gyroscopic system that can provide stabilization of marine vessels even while the vessel is not being propelled. Further, there is a need for such a system that is relatively lightweight during manufacture and installation. Still further, there is a need for such a system that utilizes abundantly available seawater as the spinning mass during operation. Finally, there is a need for such a system that is capable of offloading the seawater when the vessel is moving, thereby minimizing fuel usage.

SUMMARY

[0020] The present disclosure provides embodiments of a vessel stabilizing apparatus. The vessel stabilizing apparatus operates as a "hydrogyroscope." In this respect, the apparatus includes a liquid container secured along the hull of a floating vessel. The liquid container has a flow path therein for liquid. The liquid flow along the flow path serves as the rotor for the gyroscope.

[0021] A means is provided for inducing rotational movement of the liquid. The rotational motion of the liquid induces gyroscopic stabilization of the vessel. In certain embodiments, a valve is provided along the liquid container for receiving liquid into the rotational flow path of the container. The valve serves as a through-opening for liquid into the container, allowing the operator to optionally fill the liquid container with water from the marine environment after the floating vessel has been located at a desired position in the water. Where the marine environment is an ocean body, the operator may take advantage of the abundantly available seawater for filling and emptying the liquid container.

[0022] The means for inducing rotational flow of the liquid within the liquid container may take different forms. In one embodiment, the means is a mechanical

motor having a drive shaft. The drive shaft is operatively connected to the liquid container at a first end. In this manner, the liquid container and the liquid therein may be rotated at a high speed. Friction between the inner diameter of the liquid container and the liquid itself induces and maintains rotational motion of the liquid. Alternatively, the means for inducing rotational flow of the liquid within the liquid container may be a hydraulic motor, or pump. The pump operates to continuously circulate liquid within the liquid container in an angular flow path. Each device serves as an alternative form of a "movement device" for imparting movement to a fluid within the liquid container.

[0023] Opposing frame support members securable to the hull of a floating vessel are provided to support the liquid container. The frame members provide bearing connections with the liquid container, forming a gimbal axis about which the liquid container may precess. If the operator desires to stabilize the vessel as to roll, the frame support members are secured to the hull of the vessel at an orientation that is orthogonal to the length (or major axis) of the vessel. If the operator desires to stabilize the vessel as to pitch, the frame support members are secured to the hull of the vessel at an orientation that is parallel to the major axis of the vessel. Optionally, the operator may employ a pair of hydrogyroscopes so that the vessel may be simultaneously stabilized as to roll and pitch.

[0024] The liquid container of the vessel stabilizing apparatus may take various shapes. In one embodiment, the liquid container has a rotational axis and is rotated by a motor and connected shaft. The container is connected at a point along its rotational axis to a gimbal frame. The gimbal frame includes gimbal connections secured between first and second frame support members. The frame support members, in turn, are secured to the hull of the vessel.

[0025] In another embodiment, the liquid container is a circular tube, or "annular ring." Liquid within the container is rotated by use of one or more pumps. In this embodiment, the liquid container itself need not rotate. The annular ring liquid container is secured by gimbal connections between first and second frame support members. The frame support members, in turn, are secured to the hull of the vessel.

The opposing frame support members provide bearing connections with the liquid container, forming a gimbal axis about which the liquid container may precess.

[0026] In addition, the hydrogyroscope can be operated as an "active" system. The "active" system employs a hydrogyroscope as described above, in conjunction with a gear system mounted on the gimbal axis of the hydrogyroscope. The gear system may include a first gear for moving the hydrogyroscope about the gimbal axis, and a second gear for turning the first gear. A precessional motor is mounted to one of the support frames for moving the first gear. In addition, a small gyroscope may be mounted on the pitch or roll axis of the vessel, and a feedback control system provided that allows the small gyroscope to activate the precessional motor to force precession of the large hydrogyroscope when rolling and/or pitching motion is detected.

[0027] A floating vessel is also provided. The floating vessel includes a hull. The floating vessel also includes a vessel stabilizing apparatus as described above in various embodiments.

[0028] In addition, a method for stabilizing a floating vessel is provided. In one embodiment, a liquid container is provided along the hull of a floating vessel. The liquid container may be as described above, and receives liquid therein. The liquid container is secured to the hull of the floating vessel through a gimbal frame and axis, and then through opposing frame support members. The floating vessel is moved to a desired location in a marine body, such as the ocean. The liquid container is filled with liquid such as sea water. In one aspect, this occurs after the vessel has been moved to the desired location and moored. A motor is provided to actuate rotational movement of the liquid within the liquid container. The motor may be a mechanical motor as described above, causing rotational movement of the liquid container relative to the hull of the floating vessel. Alternatively, the motor may be a hydraulic motor, or pump, that circulates liquid within the liquid container. Also, the hydrogyroscope can be a "passive" system wherein it precesses after encountering torque applied from rolling or pitching motion, or it can be an "active" system wherein a mechanism is provided to force the hydrogyroscope to precess.

[0029] The hydrogyroscope and methods provided herein have utility in connection with numerous types of vessels. These include, but are not limited to, pleasure boats, offshore rescue craft, seismic vessels, tankers (such as a membrane-type LNG tanker), offshore workboats (including a drillship), buoys (such as a CALM buoy), a SPAR and oceanographic survey vessels.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030] Figure 1 presents a cross-sectional front view of the hull of a vessel. The vessel in Figure 1 is a ship-shaped vessel. A "hydrogyro" vessel stabilizing apparatus, in one embodiment, is presented within the ship's hull. This embodiment depicts a "passive" configuration."

[0031] Figure 2 is a plan view of the vessel stabilizing apparatus of Figure 1. Arrow R denotes the direction of rotation for the liquid container.

[0032] Figure 3 provides an enlarged perspective view of a vessel stabilizing apparatus, in an alternate embodiment. In this embodiment, the gimbal frame itself is a cylindrical body.

[0033] Figure 4 presents a top view of a "hydrogyro" vessel stabilizing apparatus, in yet an additional alternate embodiment. In this arrangement, the liquid container defines an annular ring. The annular ring may be secured between frame support members within the hull of a vessel, or may be secured to the hull outside of the vessel.

[0034] Figure 5A presents yet an additional alternate embodiment of a hydrogyroscope. In this embodiment, the "hydrogyro" is part of an "active" system. A front view of the active gyroscopic system is shown. Figure 5B is a side view of the gyroscopic system of Figure 5A. Here, the gear system is more clearly seen. Finally, Figure 5C is a plan view the gyroscopic system of Figure 5A.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Definitions

[0035] The following words and phrases are specifically defined for purposes of the descriptions and claims herein. To the extent a claim term has not been defined, it should be given its broadest definition that persons in the pertinent art have given that term as reflected in printed publications, dictionaries and issued patents.

[0036] “Hydrogyroscope” means a gyroscope that operates through the use of a spinning liquid mass, and that includes a liquid container preferably having a valve.

[0037] “Valve” means any through-opening provided for receiving liquid into the liquid container, or removing liquid from the container. Non-limiting examples of through-openings include a threaded connector, a quick-connect connector, or other connector for connecting a hose to the through-opening. The valve may have a flapper member, membrane or plate biased to seal the through-opening.

[0038] “Chamber” means any cavity, bladder or opening within a liquid container.

[0039] “Rotational flow path” means any rotational motion of liquid either by the action of a rotating chamber or along an inner diameter of a stationary chamber.

[0040] “Liquid” means any liquid. “Ambient water” means water taken from the marine environment in which a floating vessel is located. An example is seawater from an ocean body. Another example is fresh water taken from a large lake.

[0041] “Motor” means any type of motor, including a mechanical motor such as one that rotates a drive shaft, or a hydraulic pump that pumps liquid.

[0042] “Inner diameter” means an inner surface of a container wall, regardless of profile.

[0043] “Movement device” means a device that imparts movement to a fluid. Non-limiting examples of a movement device include a pump and a mechanical shaft driven by a motor.

Description of Specific Embodiments

[0044] A description of certain embodiments of the inventions is presented below.

[0045] In one embodiment, a vessel stabilizing apparatus is provided. The apparatus comprises a liquid container securable to a floating vessel; means for urging the liquid to spin within the liquid container relative to the floating vessel in order to stabilize the floating vessel within a marine body; and opposing frame support members securable to the hull of a floating vessel, the frame members providing bearing connections with the liquid container forming a gimbal axis about which the liquid container may precess. The vessel stabilizing apparatus may further comprise a gimbal frame for supporting the liquid container, with the gimbal frame having at least one connector connected to the liquid container along an axis of rotation of the liquid container; and wherein the bearing connections of the opposing frame support members are connected to the gimbal frame so that the gimbal frame may precess with the liquid container about the gimbal axis. In one aspect, the means for urging the liquid to spin relative to the floating vessel comprises a mechanical motor; and a drive shaft rotated by the motor, the drive shaft being operatively connected to the container in order to frictionally impart rotational movement to liquid when liquid is placed within the liquid container.

[0046] In one embodiment, a method for stabilizing a floating vessel is provided. The method comprises the steps of providing a liquid container along the hull of the floating vessel, the liquid container having a valve for receiving liquid therein; moving the floating vessel to a desired location in a marine body; filling the liquid container with water from the marine body after the floating vessel has been moved to the desired location within the marine body; providing a motor in the hull of the floating vessel; and actuating the motor in order to cause rotational movement of the water relative to the hull of the floating vessel. The liquid container may be disposed within the hull of the floating vessel; and the motor comprise a mechanical motor having a drive shaft connected to the liquid container at a first end of the container. In this arrangement, the step of actuating the motor in order to cause rotational movement of the water relative to the hull of the floating vessel comprises rotating the

liquid container relative to the hull of the floating vessel. The method may further comprise the steps of securing a first frame support member to the hull of the floating vessel, the first frame support member supporting the liquid container through a first bearing connection; and securing a second frame support member to the hull of the floating vessel, the second frame support member supporting the liquid container through a second opposing bearing connection; the first and second bearing connections providing a gimbal axis about which the liquid container may precess.

[0047] In another aspect, the present invention provides a floating vessel. The floating vessel comprises a hull; and a hydrogyroscope, comprising a liquid container disposed along the hull of the floating vessel, the liquid container having a rotational flow path therein, and a valve along the liquid container for receiving liquid into the rotational flow path of the liquid container. In this arrangement, the floating vessel may further comprise opposing frame support members securable to the hull of the floating vessel, the frame members providing bearing connections with the liquid container forming a gimbal axis about which the liquid container may precess.

[0048] In another aspect, the present invention provides an active gyroscopic system for stabilizing a vessel having a hull. The active gyroscopic system comprises a liquid container securable to the vessel, the liquid container having a gimbal shaft about which the liquid container rotates; a first mechanical motor; a drive shaft rotated by the motor, the drive shaft being operatively connected to the liquid container in order to frictionally impart rotational movement to liquid within the liquid container; opposing frame support members securable to the hull of the vessel, the frame members supporting the liquid container through the gimbal shaft; a first gear operably connected to the shaft of the liquid container; a motion sensing apparatus for sensing motion of the vessel; a second gear constructed and arranged to impart rotational movement to the liquid container through the first gear; a second mechanical motor for rotating the second gear; and a controller sensing motion of the gyroscope and sending a signal to the second mechanical motor to rotate the second gear in a desired direction, thereby forcing the liquid container to rotate about the

gimbal shaft so as to stabilize the vessel. In one embodiment, the motion sensing apparatus comprises a gyroscope.

Description of Embodiments Shown in the Drawings

[0049] An illustrative apparatus for stabilizing a vessel is shown at **100** in **Figure 1**. **Figure 1** presents a vessel stabilizing apparatus **100** within a vessel **10**. The hull **12** of the vessel **10** is shown in cross-section. The vessel **10** in **Figure 1** is a ship-shaped vessel. However, it is understood that the vessel **10** may be of any shape. For example, a non-ship-shaped vessel such as an offshore working platform may utilize a vessel stabilizing apparatus **100**.

[0050] The vessel stabilizing apparatus **100** operates as a "hydrogyroscope." The hydrogyroscope **100** includes a liquid container **110** disposed at a point along the hull **12** of the floating vessel **10**. In the arrangement of **Figure 1**, the liquid container **110** is placed within the hull **12** of the vessel **10**. The liquid container **110** may be positioned anywhere within the hull **12** of the vessel **10**. In one arrangement, the liquid container **110** will be placed at either the vessel roll axis for stabilizing against roll or the vessel pitch axis for stabilizing the vessel **10** against pitch.

[0051] The particular container **110** of **Figure 1** is configured to rotate about a rotational axis. The rotational axis of the container **110** is defined by a shaft **112**. The illustrative container **110** is shaped as a cylinder. While a cylindrical arrangement is provided in **Figures 1** and **2**, it is understood that any symmetrical container for spinning a liquid mass may be employed.

[0052] The cylinder **110** of **Figure 1** has an internal chamber **115** for receiving liquid. At least one valve **116** is provided along the outer chamber wall **110'** of the liquid container **110** for receiving liquid into the inner chamber **115**. In the arrangement of **Figure 1**, two separate valves **116', 116''** are provided. The valves **116', 116''** are disposed on opposite sides of the container **110** and are equidistantly positioned from the shaft **112** for balancing the liquid container **110** when it is rotated at high speeds. The valves **116', 116''** serve as through-openings for moving liquid into or out of the annular chamber **115**, allowing an operator to optionally fill the

annular chamber **115** with ambient water after the floating vessel **10** has been located at a desired position in the marine environment. Where the marine environment is an ocean body, the operator may take advantage of the abundantly available seawater for filling the liquid container **110**. In the view of **Figure 1**, valve **116'** represents an inlet valve, while valve **116''** represents an offloading valve; however, the function of the valves **116'**, **116'** may be interchangeable.

[0053] The vessel stabilizing apparatus **100** is permitted to precess about a gimbal axis. In the arrangement of **Figure 1**, the liquid container **110** is connected to a gimbal frame **130**, which in turn includes gimbal connections **122**, which will be described further below. The gimbal frame **130** defines a sturdy structural frame that is connected to the liquid container **110**. A connector **132** is seen in **Figure 1** providing fixed movement between the liquid container **110** and the gimbal frame **130** in the plane of the longitudinal axis of the vessel **10**. The connector **132** resides along the rotational axis of the liquid container **110** at either end (or both ends) of the container **110**. A bearing **134** is provided at the interface between the gimbal frame **130** and the connector **132**. The bearing **134** allows the liquid container **110** to rotate relative to the gimbal frame **130** around an axis that is essentially vertical to the hull **12** of the vessel **10** when the hydrogyroscope is not precessing.

[0054] In the arrangement of **FIG. 1**, the gimbal bearing **134** is shown extending below the gimbal frame **130**. In practice, the bearing **134** may reside within a recess (not shown) of the frame **130**. Alternatively, the bearing **134** may be placed below the frame connector **132**. The extending bearing **134** arrangement is provided for illustrative purposes.

[0055] As mentioned, the gimbal frame **130** provides a gimbal axis which permits the spinning liquid container **110** to precess. In the arrangement of **Figure 1**, the gimbal frame **130** includes gimbal connections **122** secured between first and second frame support members **120**. The gimbal connections **122** form the gimbal axis for the liquid container **110**. Each of the gimbal connections **122** includes a bearing **124** that provides relative rotational movement between the gimbal frame **130** and the

frame support members **120**. The frame support members **120**, in turn, are secured to the hull **12** of the vessel **10**.

[0056] A means is provided for inducing rotational motion of the liquid within the inner chamber **115** of the container **110**. In the embodiment of **Figure 1**, the means is a motor **M**. The motor **M** is a mechanical motor, and may be either electrically powered, steam powered, hydraulically powered, or powered by a hydrocarbon fuel. In **Figure 1**, the motor **M** is connected to the shaft **112** and mounted to the gimbal frame **130**. This allows the liquid container **110** to precess along the major axis of the vessel **10**.

[0057] **Figure 2** is a plan view of the vessel stabilizing apparatus **100** of **Figure 1**. This figure is provided to demonstrate the relative rotational movement generated by the motor **M** (of **Figure 1**) on the liquid container **110**. Arrow **R** denotes the clockwise direction of rotation for the container **110**. Of course, the direction of rotation may be either clockwise or counterclockwise. It can be more readily seen that the container **110** rotates relative to the gimbal frame **130** and the opposing frame support members **120**. The bearing **134** is also visible through the gimbal frame **130**.

[0058] In operation, the liquid container **110** serves as a hydrogyro rotor. Preferably, and as will be discussed more fully below, the liquid container **110** is filled with seawater after the vessel has been transported to a desired location offshore. The hydrogyro filled with seawater spins about the rotational axis using power from the motor **M**. The bearings **134** and connector **132** provide lateral support for the liquid container **110** relative to the gimbal frame **130**, while allowing rotational movement of the liquid container **110**. The liquid container **110**, gimbal frame **130** and motor **M** are free to precess on the gimbal axis provided by the gimbal frame connectors **122**. For example, when stabilizing against the rolling motion caused by a wave, the motor **M** would swing like a pendulum into and out of the page in the view of **Figure 1**.

[0059] When the hydrogyro **100** senses torque translated from the ship hull **12** to the gimbal frame **130** and then to the gimbal axis **122**, the liquid container **110** precesses about the gimbal axis **122**.

[0060] **Figure 3** provides an enlarged perspective view of a vessel stabilizing apparatus **100'**, in an alternate embodiment. In this embodiment, the gimbal frame **130** is a cylindrical body. The cylindrical body configuration for the gimbal frame **130** provides a measure of safety in the event that the liquid chamber **115** loses integrity, particularly while rotating at a high speed. In addition, the cylindrical body configuration for the gimbal frame **130** provides a measure of safety in the event that the shaft **112** should break during rotation.

[0061] In the arrangement of **Figure 3**, a connector arrangement can be seen between the gimbal frame **130** and the gimbal connections **122**. The connector arrangement is shown at **126**, and comprises a plate with bolts **127**. A bearing **124** is provided between the gimbal connections **122** and the opposing frame members **120**. It is understood that other connector arrangements may be utilized. Indeed, the present invention is not limited to the manner in which various mechanical connections are arranged, including the manner in which the shaft **112** is connected to the liquid container **110**, the manner in which the gimbal frame **130** is connected to the liquid container **110**, or the manner in which the gimbal frame **130** is connected to the frame supporting members **120**.

[0062] The illustrative cylinder **110** of **Figure 3** employs an annular chamber ring **115** or circular ring configuration in which the liquid is retained. The optional chamber ring **115** increases the mean radius of rotation for the spinning liquid mass, thereby potentially increasing the stabilizing torque available to be applied to the vessel **10**. A vacated inner region **117** is defined around the shaft **112**. An inner chamber wall **114** is provided to separate the liquid chamber **115** from the vacated inner region **117**. In the arrangement of **Figure 3**, the inner chamber wall **114** is circular in profile, and is disposed concentrically within the outer chamber wall **110'** to provide an annular flow path for liquid. However, it is preferred that the vacated inner region **117** be small or non-existent.

[0063] In the embodiments of **Figures 1** and **3**, rotational movement of the liquid within the liquid container **110** is induced by rotating the liquid container **110** about its rotational axis. Friction between the inner surface of the container **110** and the liquid contained therein urges the liquid to move in a rotational path relative to the hull **12** of the vessel **10**. Rotational motion of the liquid container **110** is provided by actuating the mechanical motor **M** and connected drive shaft **112**. As liquid travels along the inner surface of the outer chamber wall **110'**, angular momentum is created around the rotational axis of the container **110**. This, in turn, creates precessional forces within the floating vessel **10**. Because the frame supporting members **120** are secured to the hull **12** of the vessel **10**, gyroscopic forces generated by the hydrogyroscope **100** are transmitted to the vessel **10**.

[0064] As an alternative embodiment, rotational movement of liquid within the liquid container **110** may be induced by continuously circulating liquid into and through the liquid container **110**. In such an arrangement, the motor defines one or more hydraulic pumps that pump liquid into the liquid container **110** at high velocity. An example of such an arrangement is seen in **Figure 4**.

[0065] **Figure 4** presents a top view of a "hydrogyro" vessel stabilizing apparatus **100''** in an additional alternate embodiment. This alternate embodiment of a hydrogyro vessel stabilizer would preferably be used in non-ship-shaped vessels. Examples of such a vessel would be a SPAR, a CALM buoy, or even a workboat that includes a working platform. In this arrangement, the liquid container **110** defines an annular ring. The annular ring **110** is secured between frame support members **120** within the hull of a vessel, or may be secured to the hull outside of the vessel (not shown). In this latter arrangement, the frame members would be the hull of the vessel itself, and would reside within the inner diameter of the ring **110**. In the arrangement of **Figure 4**, frame support members **120** are represented within the hull of a vessel (not shown). In such an arrangement, a gimbal frame is not required separate from the liquid container **110**. In this respect, a gimbal connection **122** is provided immediately between the liquid container **110** and each of the opposing frame support

members **120**. Each gimbal connection **122** includes a bearing **124** that allows the liquid container **110** to precess relative to the frame support members **120**.

[0066] In the embodiment of **Figure 4**, two separate pumps **P** are shown. The pumps **P** pump fluid, e.g., seawater, within the liquid container **110** in the direction shown by arrows **R**. Helically arranged fins (not shown) may optionally be disposed along an inner diameter of the container **110** to aid in moving seawater in an angular path. However, it is preferred that no obstructions be placed within the flow path of the liquid. It is understood that the arrangement of **Figure 4** preferably includes inlet and outlet lines in fluid communication with the pumps **P**. In **Figure 4**, line **142** is provided as a fluid inlet line, while line **144** is provided as a fluid outlet line. The fluid source is the readily available ambient water. The lines **142, 144** allow draining and filling of the ring **110**, and also provide a means of controlling any heat buildup that would result from continuously circulating a fluid through pumps **P**.

[0067] Once positioned at a desired location in a marine body, the vessel is moored using an anchor or mooring lines. Depending on the nature of the vessel, optional strakes and support trusses may be employed for the vessel in connection with the hydrogyroscope of **FIG. 4**. Such a vessel stabilizing apparatus allows pumping of ambient water inside the rotational tube along a larger radius, thereby creating high angular momentum forces. This permits useful gyroscopic forces to be applied to large working platforms offshore. The stabilizing torque provided by a gyroscope is directly proportional to the rotor mass, angular velocity of rotation, and angular velocity of precession, but it is also proportional to the square of the rotor radius. Therefore, the rotor radius has a much greater influence on the stabilizing torque than any other factor.

[0068] The following equations will shed additional light on the relationship of rotor radius, fluid mass velocity, and rate of precession. A spinning mass tends to remain within its plane of rotation unless acted upon by an external force. The formula for stabilizing torque provided by a gyroscope is:

$$\tau = I \times W_s \times W_p$$

where:

I is the moment of inertia which, for a cylinder, is defined by $I = ½\ \text{mass} \times r^2$;

mass is the mass of the spinning cylinder (which may be the weight of the water plus the weight of the container);

r is the radius of the spinning cylinder;

W_s is the angular velocity of the hydrogyroscope;

W_p is the angular velocity of precession of the hydrogyroscope when subject to an excitation torque equal to the stabilizing torque; and

When mass is in pounds (lbs) and radius is measured in feet (ft), I is given in foot-pounds-sec^2 (lb-ft-sec^2).

[0069] A May 1948 article in Westinghouse Engineer described an anti-roll gyroscope utilizing a solid spinning mass. The gyroscope was deployed in a 5,000 ton yacht. The article stated that the yacht required a stabilizing torque of 2,500,000 lb-ft for passenger comfort in rough seas. This information was used to estimate that 500 lb-ft stabilizing torque/ton vessel is needed. Based upon this value, and adapting this information to a spinning fluid mass, calculations can be made for the amount of stabilizing torque that a gyroscope should supply for passenger comfort, along with specifications for a hydrogyroscope to supply the necessary torque. A hydrogyroscope in accordance with the above-described embodiments can be designed with the following specifications:

Mass of Vessel (in tons)	Stabilizing Torque Needed (in lb-ft)	No. of Gyros.	Ws (in rpm)	Wp (in deg/sec)	Radius of Cylinder (in ft)	Mass of Gyroscope (in lbs)	Thickness of Cylinder (in ft)
5	2,500	1.0	2000	5	3	979	0.50
50	25,000	1.0	2000	5	4	5,506	1.71
100	50,000	1.0	2000	5	4	7,047	1.40
500	250,000	1.0	2000	5	7	17,977	1.82
1,000	500,000	1.0	2000	5	9	21,750	1.34
2,500	1,250,000	1.0	2000	5	10	44,044	2.19
5,000	2,500,000	1.0	2000	5	11	72,801	2.99
10,000	5,000,000	1.0	2000	5	12	122,345	4.22
25,000	12,500,000	1.0	2000	5	13	260,617	7.67
50,000	25,000,000	1.0	2000	5	14	449,432	11.40
100,000	50,000,000	1.0	2000	5	15	783,010	17.30
250,000	125,000,000	1.67	2000	5	16	1,029,759	20.00
500,000	250,000,000	2.62	2000	5	17	1,162,501	20.00
1,000,000	500,000,000	4.17	2000	5	18	1,303,288	20.00
5,000,000	2,500,000,000	13.7	2000	5	20	1,608,998	20.00
7,500,000	3,750,000,000	16.9	2000	5	21	1,773,920	20.00
10,000,000	5,000,000,000	18.7	2000	5	22	1,946,888	20.00

[0070] Based upon the foregoing description, those of ordinary skill in the art will appreciate that the hydraulic vessel stabilization apparatus may also employ a hydraulic rotor to act as an *active* ship gyrostabilizer. In one aspect, this would be used after the vessel has been moored.

[0071] **Figure 5A** presents yet an additional alternate embodiment of a hydrogyroscope. A front view of the gyroscopic system **500** is shown. As with the passive system **100** of **Figure 1**, a spinning liquid container **110** is provided. Rotational movement of the liquid container **110** is again provided by a motor **M** and a connected shaft **512**. The liquid container **110** is again supported by a gimbal frame **530** and holds a fluid mass within a chamber **115**. The chamber **115** provides an internal flow path in which fluid rotationally travels. The gimbal frame **530**, in turn, is disposed between two opposing frame members **120**, and suspended by a shaft **122** forming a gimbal axis. However, unlike the "passive" system of **Figure 1**, in the

embodiment of **Figure 5A** the spinning liquid container **110** is provided as part of an "active" system.

[0072] The active system **500** of **Figures** 5A and **5B** include a gear system **520**. In the arrangement of **Figure 5A**, the gear system **520** includes a first gear **524** connected to the gimbal axis **122**. The first gear **524** turns in response to rotational mechanical force (such as by teeth) provided from a second gear **522**. The second gear **522**, in turn, is driven by a precession motor **510**. Thus, movement by the precession motor **510** forces the gimbal frame **530** to turn, thereby creating precessional forces on the vessel (not shown in **Figure 5A**).

[0073] **Figure 5B** is a side view of the gyroscopic system **500** of **Figure 5A**. Here, the gear system **520** is more clearly seen. Interlocking teeth **521**, **523** from the first **524** and second **522** gears are seen, respectively.

[0074] The active gyroscopic system includes a separate, smaller gyroscope **550**. The smaller gyroscope **550** is provided to sense rolling motion and/or pitch on the vessel. A controller **540** is provided that senses precessional forces generated by the smaller gyroscope **550**. These precessional forces are then converted into electrical signals by the controller **540**. The controller **540** is in electrical communication with the precession motor **510** by wires **511**, and sends instructions to the precession motor **510** to turn the second gear **522** clockwise or counterclockwise, depending upon which precessional forces are to be applied by the spinning liquid container **110**.

[0075] The smaller gyroscope **550** may be of any kind. However, it is preferred that it be a small gyroscope that weighs as little as a few ounces. The smaller "gyro" **550** is more sensitive to vessel movement, and permits highly responsive sensing by the controller **540**. This allows the larger spinning "hydrogyro" container **110** to be manipulated by the gear system **520** quickly, enabling the gyroscopic system **500** to effectively counteract pitching or rolling motion, again depending upon the orientation of the frame members **120** as discussed above.

[0076] It is also noted that the use of an active gyroscopic system allows precessional forces to be generated with a smaller spinning liquid mass. In this

respect, the second gear **522** can act on the first gear **524** to provide a higher angular velocity (W_p) for the liquid container **110** about the gimbal axis **122**. Per the formula set forth and discussed above, an increase in W_p permits a decrease in the moment of inertia (I) and/or angular velocity of the hydrogyroscope (W_s).

[0077] Finally, **Figure 5C** is a top view the gyroscopic system **500** of **Figure 5A**. Arrow **R** indicates the direction of rotation of the liquid container **110**. Of course, the container **110** may be urged by the motor **M** to spin in either direction.

[0078] It can be seen from **Figures 5A-5C** that an active gyroscopic system for stabilizing a vessel is provided. In one aspect, the system **500** comprises a liquid container securable to a floating vessel. The liquid container **110** has a gimbal shaft **122** about which the liquid container **110** may rotate. The system **500** also includes a first mechanical motor **M** and a drive shaft **112** rotated by the motor **M**. The drive shaft is operatively connected to the liquid container **110** in order to frictionally impart rotational movement to liquid within the liquid container **110**. Opposing frame support members **120** are provided. The frame support members **120** are securable to the hull of a vessel. The frame members support the liquid container **110** through the gimbal shaft **122**. A first gear **524** is operably connected to the shaft **122**.

[0079] Next, a motion sensing apparatus **550** is provided for sensing motion of the vessel. The motion sensing apparatus **550** may be a gyroscope, a pendulum or other device. Preferably, a small gyroscope is utilized as the sensing apparatus **550**. A second gear **522** constructed and arranged to impart rotational movement to the liquid container **110** through the first gear **524** is provided. In addition, a second mechanical motor **510** for rotating the second gear **522** is provided. A controller **540** senses motion of the gyroscope **550**, and sends a signal to the second mechanical motor **510** to rotate the second gear **522** in a desired direction. In this way, the liquid container **110** is forced to rotate about the gimbal shaft **122** so as to stabilize the vessel.

[0080] Referring back to the arrangement of **Figure 1**, the frame support members **120** are secured to the hull **12** of the vessel **10** at an orientation that is orthogonal to the length (or major axis) of the vessel **10**. This provides stabilization of the vessel **10**

as to roll. If the operator desires to stabilize the vessel **10** as to pitch, the frame support members **120** are secured to the hull **12** of the vessel **10** at an orientation that is parallel to the length of the vessel **10**. In one arrangement, a pair of vessel stabilizing apparatuses **110** is provided in the hull **12** of the vessel **10**, with one being positioned to stabilize the vessel as to pitch forces, and the other being positioned to stabilize the vessel as to roll forces. In another arrangement, a single hydrogyroscope may be employed, with the hydrogyroscope being rotatable within the hull of the vessel. For example, the opposing frame support members could be placed on a circular track and given freedom to move in a circular plane. In this way, a single hydrogyroscope (whether active or passive) may be employed to stabilize the vessel both as to pitch forces and as to roll forces.

[0081] A method is also provided for stabilizing a floating vessel. In one embodiment, a liquid container is secured to the hull of a floating vessel. The liquid container may be as described above, and receives liquid therein. The liquid container is secured to the hull of the floating vessel. The floating vessel is moved to a desired location in a marine body, such as the ocean. The liquid container is filled with liquid such as sea water. Preferably, this occurs after the vessel has been moved to the desired location and moored. A motor is provided to actuate rotational movement of the liquid within the liquid container. The motor may be a mechanical motor as described above, causing rotational movement of the liquid container relative to the hull of the floating vessel. Alternatively, the motor may be a hydraulic motor, or pump, that continuously circulates liquid within the liquid container along a rotational flow path.

[0082] The present inventions provide improvements over known active and passive gyroscope stabilizer systems because, among other improvements, they incorporate a water-filled rotor (hydrogyroscope) or spinning liquid mass rather than a solid metal mass. One benefit of a spinning liquid mass is that the water can be offloaded when the stabilizing force is not needed. For example, when a vessel is moored and rolling motions cause a concern for passenger safety or operational integrity, the hydrogyroscope can be filled with water and put into operation. When

the vessel is in transit and the stabilization provided by the hydrogyroscope is not needed, the water can be discharged, thereby reducing the vessel mass and conserving energy and fuel.

[0083] The hydrogyroscope has application to all floating vessels and structures that require stability. A large hydrogyroscope will stabilize a very large vessel, while a smaller hydrogyroscope can stabilize a small pleasure craft, racing boat or rescue boat. For example, a hydrogyro mounted with the gimbal axis parallel to the major axis of the vessel would act to counteract any sudden change in vessel attitude caused by choppy water and thereby decrease the possibility of a boat becoming airborne.